300-mK Strap System

Subsystem Development Plan

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1. Scope

The Herschel/SPIRE 300-mK Strap System provides the thermal link between the Sorption Cooler interface and the three Photometer BDAs and the two Spectrometer BDAs. It includes the following items of hardware:

1. The support structure that locates and supports the strap,
2. The Cooler – Photometer BDA Strap,
3. The Cooler to Spectrometer BDA Strap,
4. The Photometer Detector Box Stray Light Baffle,
5. The Spectrometer Detector Box Stray Light Baffle,
6. The electrically isolating / thermally conductive joint at the cooler interface, and
7. The Photometer Thermal Control Hardware.

The interfaces that have to be managed during the development of the system include:

1. The two 300-mK Strap Supports (BBS-PMW and BBS-PLW) to the Photometer Detector Box,
2. The interface between the Photometer Detector Box and the Photometer Detector Box Stray-Light Baffle (SLB-Phot.)
3. The interface between the Spectrometer Detector Box and the Spectrometer Detector Box Stray-Light Baffle (SLB-Spect.)
4. The interface between the 300-mK Straps and the Sorption Cooler.
5. The interface between the 300-mK Straps and the BDAs
6. The interface between the 300-mK Straps and the PTC cryogenic hardware.

2. Documents

2.1 Applicable documents

	Title	Author	Reference
AD1	SPIRE 300-mK Straps System Requirements Document	D Griffin	SPIRE-RAL-PRJ-001323
AD2	Instrument Requirements Document	B.M.Swinyard	SPIRE-RAL-PRJ-000034 Issue 0.30
AD3	SPIRE Calibrators & Filters Product Assurance Plan	P. Hargrave	HSO-CDF-PL-007 Issue 1.0 15 November 2001
AD4	SPIRE – STRUCTURE PRODUCT ASSURANCE PLAN	A Dibbens	MSSL/SPIRE/PA001.02
AD5	SPIRE Product Assurance Plan	D. Kelsh, G. Douglas	SPIRE-RAL-PRJ-000017
AD6	SPIRE Major Milestone List	K. King	DOCUMENT No: SPIRE-RAL-PRJ-000455, Issue 1.3 Draft 1.

2.2 Reference documents

	Title	Author	Reference
RD1	Instrument development plan	K.J.King	
RD2	Temperature Stability Requirements for SPIRE	J. Bock	SPIRE-JPL-NOT-000623
RD3	SPIRE 300-mK Strap System Design Description	P. Hargrave	HSO-CDF-DD-038

3. Glossary

AD	Applicable Document
BDA	Bolometer Detector Assembly
CDR	Critical Design Review
DDR	Detailed Design Review
DM	Development Model
FPU	Focal Plane Unit
FS	Flight Spare
MGSE	Mechanical Ground Support Equipment
MSSL	Mullard Space Science Laboratory
PFM	ProtoFlight Model
PTC	Photometer Thermal Control
RAL	Rutherford Appleton Laboratory
RD	Reference Document
SLB	Stray-Light Baffle
SLB-Phot.	Photometer Detector Box Stray Light Baffle
SLB-Spect.	Spectrometer Detector Box Stray Light Baffle
TMM	Thermal Mathematical Model
TSS	300-mK Strap Support
TSS-PLW	The 300-mK Strap Support inside the Photometer Detector Box mounted near the PLW BDA
TSS-PMW	The 300-mK Strap Support inside the Photometer Detector Box mounted near the PMW BDA
UCF	University of Wales, Cardiff

4. Organisation

There are three main institutions involved in the development and delivery of the 300-mK Strap System, viz.,

- The Mullard Space Science Laboratory (MSSL),
- The University of Wales, Cardiff (UCF) and
- The Rutherford Appleton Laboratory (RAL).

The ultimate responsibility for the delivery of the 300-mK Strap System remains with MSSL. Both UCW and RAL will assist MSSL in various aspects of the development of the subsystem. These are detailed below in Table 1.

The Photometer Thermal Control hardware is a set of heaters and thermistors that are mounted directly on the 300-mK straps that are used to reduce the amplitude of the temperature variations of the BDAs during certain operating modes of the photometer. JPL is responsible for this design and procurement of this equipment. During the first half of the SPIRE CQM programme, the temperature variations of the BDA will be measured. If the amplitude of the temperature variations in a specified frequency band exceeds a predetermined limit, then the PTC system will be designed and integrated with the instrument. If the variations do not exceed the limits or the results remain inconclusive, then the system will not be incorporated.

Table 1 - Division of responsibilities for the development of the 300-mK Strap System.

Institution	Responsibilities	Details
MSSL	Mechanical Design	Structural analysis of the system
	Manufacture and AIV	• Manufacture of the 300-mK System excluding the Stray-Light Baffles and 300-mK Strap Supports. • Integration of the entire 300-mK System into SPIRE using pre-integrated Stray-Light Baffles and 300-mK Strap Supports.
	Mechanical Testing	Supervision of the vibration testing of the entire system
Cardiff	Thermal testing	Thermal conductivity of prototype materials
		Thermal interface study – to find optimal interface configuration.
		Thermal testing of prototype 300mK system.
	Optical testing	Testing the performance of prototype stray light baffles.
	Manufacture and AIV	Manufacture and AIV of the Stray-Light Baffles and the 300-mK Strap Supports.
RAL	Thermal modelling	Evaluation of the thermal design of the system
	Stray-Light Analysis	Evaluation of the optical suitability of the Stray-Light Baffles design
JPL	PTC	Design, AIV and testing of the PTC Hardware

5. Product Assurance

The SPIRE PA Plans applicable to each institution applies to the delivery of this system.

6. System Description

A full description of the system can be found in the Document HSO-CDF-DD-038– SPIRE 300-mK Strap System Design Description [RD3].

The 300-mK straps are used to thermally connect the Sorption Cooler cold tip to the BDAs. The main design requirements on the system can be summarised as follows[1].

1. The thermal conductivity must be sufficient to maintain the temperature of interface with the BDAs within 20mK of the temperature of the Cooler Tip under nominal operating conditions.
2. The system must be held rigidly so that the system is accurately located and little vibrational amplification is seen during random vibration.
3. The parasitic heat loss from the strap to the rest of the structure must be within the specified limits.
4. There must be stray light baffles that prevent the ingress of spurious light into the Photometer and the Spectrometer Detector Boxes.
5. Provision is to be made to individually electrically isolate the photometer and spectrometer straps from the cooler tip while simultaneously maintaining adequate thermal conductivity, or to alternatively isolate each BDA tail.

A thermal short in the 300-mK system represents a single point failure mode for the instrument[2].

7. Model Philosophy

7.1 Integrated 300-mK Strap System

The following complete 300-mK Strap systems will be delivered and integrated into the SPIRE.

Model	**Description**
PFM	Built to flight standard.
STM/CQM/FS	Built to flight standard. Used for the instrument level structural and thermal qualification of the subsystem. The FS is a refurbished CQM. The CQM is a refurbished STM

The STM/CQM/FS model will be used to qualify the system for use in the

[1] The definitive requirements on this system remain as documented in AD*SPIRE 300-mK Strap System Requirements*[AD1].

[2] A thermal short of the SPIRE 300-mK System is not a single point failure mode for the other Herschel instruments.

7.2 300-mK Strap Components

A pair of Stray-light baffles and a pair of strap supports will be produced and tested in parallel with the SPIRE STM programme. These components will be thermally, optically and mechanically tested and characterised by UCF.

8. Schedule Overview

The dates of the milestones for the development of the 300-mK Strap System are not contained in this document as the system falls within the ambit of the SPIRE Structure Schedule. For information, the sequence of the major milestones for the 300-mK Strap System is shown in Figure 1.

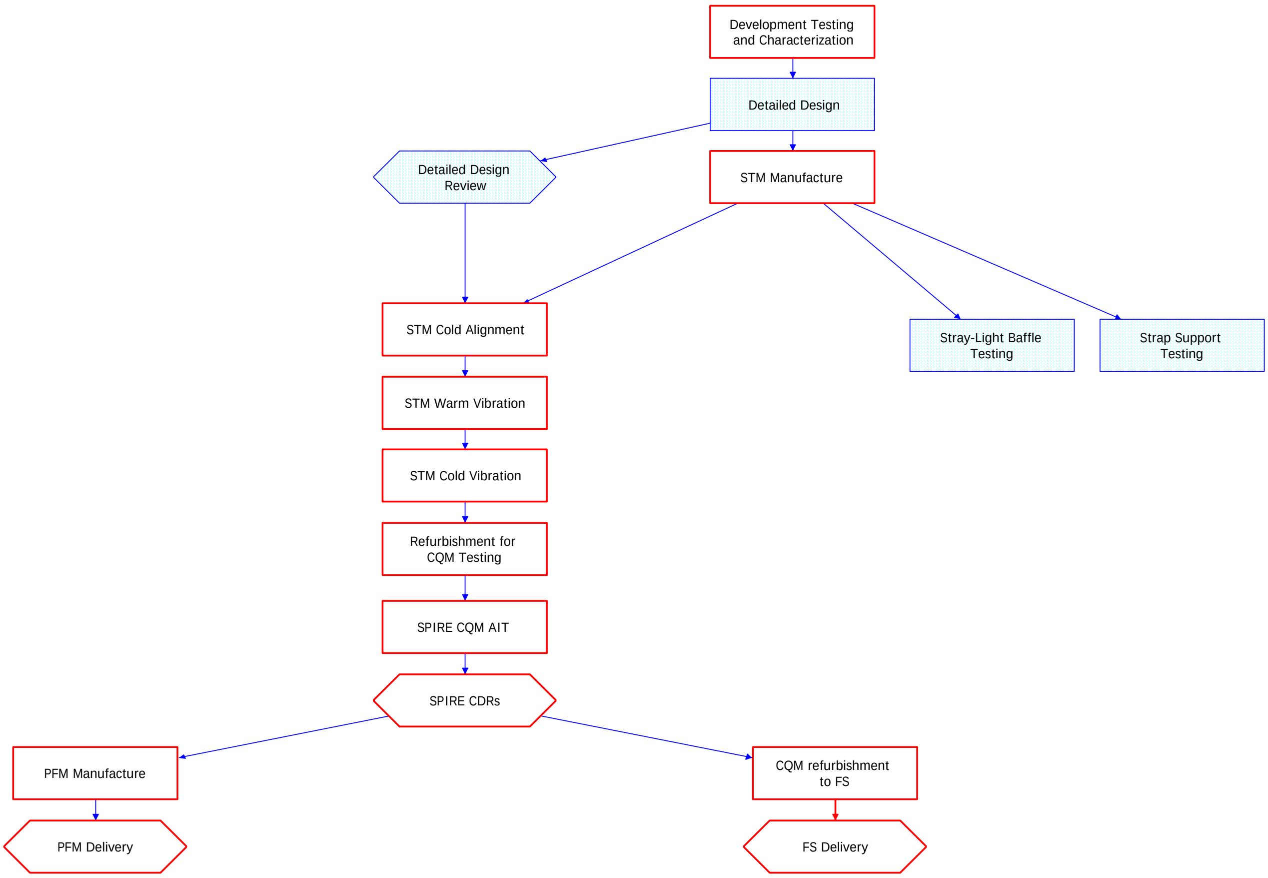

Figure 1 – Overview of the schedule sequence for the development and delivery of the 300-mK Strap System delivery.

9. Receivables - Deliverables

Item	**Model**	**From**	**To**	**Date**
Photometer Stray-Light Baffle	STM/CQM	UCF	MSSL	TBD
Spectrometer Stray-Light Baffle	STM/CQM	UCF	MSSL	TBD
Strap Supports	STM/CQM	UCF	MSSL	TBD
Integrated SPIRE Structure	STM/CQM	MSSL	RAL	TBD
Photometer Stray-Light Baffle	PFM	UCF	MSSL	TBD
Spectrometer Stray-Light Baffle	PFM	UCF	MSSL	TBD
Strap Supports	PFM	UCF	MSSL	TBD
Integrated SPIRE Structure	PFM	MSSL	RAL	TBD

10. Development Testing and Analysis Programme

There are several aspects of the design and compliance verification of the 300-mK Strap System that are sufficiently novel to require that there be significant effort spent in characterising the behaviour of the various components at representative conditions. Preferably, this is to be done by test/experiment. Where this is not possible, it will be done by analysis.

10.1 Thermal testing and analysis

There are two main design performance parameters that need to be tested; (i) the overall thermal conductivity between the cooler cold tip and, (ii) the total parasitic heat load.

10.1.1 300-mK Strap component thermal conductance

The overall thermal conductivity of the 300-mK strap system will depend on the individual conductances of the following elements:

1. Cooler-Strap I/F (this includes the conductance of the electrically isolating joint)
2. Strap bulk linear conductance (High purity copper 99.999%)
3. Strap internal joint conductance.
4. Strap-BDA I/F

All of these components have been experimentally characterized by UCF at temperatures around 300-mK using CEA and JPL interface data. The components and interfaces are to be placed in a sub-Kelvin cryostat and cooled to the normal operating temperatures. Calibrated cryogenic temperature sensors and resistive heaters will be used to measure the thermal conductance of each component in the system.

10.1.2 Parasitic heat load

The stray-light baffles and the supports are thermally isolated from the Level-0 structure of SPIRE using various diameters and lengths of Kevlar cord. Some experimental data on the thermal conductivity of Kevlar at cryogenic temperatures is available. The parasitic heat load of the final design of the stray light baffles and the strap supports will be experimentally characterized by UCF against temperature.

10.1.3 System modelling

The correlations and the design information are to be eventually inserted into the integrated SPIRE TMM. This modelling will help to establish that the thermal requirements of the system have been met and to predict the performance of the system once it is integrated into SPIRE.

10.1.4 Integrated SPIRE STM/CQM and PFM programmes

The thermal performance of the 300-mK system as an integrated system within SPIRE will be tested during the STM and the CQM programmes.

During the SPIRE STM programme, the 300-mK strap system will be integrated into the structure initially with a mass dummy cooler. This will be cooled to cryogenic temperature but no information about the thermal performance of the system will be gained during this phase. After this, the structure will undergo vibration testing, after which, a fully functional cooler will be integrated into the system. SPIRE will then be cooled to cryogenic temperature and the first correlations between the performance of the system and the SPIRE TMM will be made. These tests will however be carried out using dummy BDAs that have been designed to give similar heat loads onto the strap as the fully functional flight BDAs. The only temperature monitored during this phase of the test will be the cooler cold tip temperature.

The CQM programme will have one fully functional photometer BDA and one spectrometer BDA. The BDAs have dark bolometer NTD thermistors that will allow the measurement of the actual temperature drop between the cooler and the two installed BDAs. Correlation of these results with the SPIRE TMM will allow the more accurate determination of the compliance of the 300-mK strap system with the thermal requirements.
The final thermal qualification of the 300-mK Strap system will be during the PFM calibration programme. During these tests, all the flight BDAs will be integrated into SPIRE and the temperatures and cooler heat loads measured.

10.2 Structural

The main structural requirements relate to the ability of the system to undergo the launch loads and accelerations without damage or loss in performance. Secondary requirements are also found in the ability of the system to cool down to operating temperature without the inducing of thermal stresses on the interfaces. As with the development of the thermal design, the structural design relies on both laboratory testing and numerical analysis.

10.2.1 300-mK Support characterisation and analysis

The aspect of the structural design of the 300-mK strap system that carries the greatest level of uncertainty is the static and dynamic strength and stiffness prediction of the strap supports and the stray-light baffles. These two units both consist of an inner structure through which the 300-mK strap passes and an outer structure that is rigidly affixed to the Level-0 structure of SPIRE. These two sections are thermally isolated form each other by a three-dimensional pre-tensioned Kevlar string-up.

The prediction of the rigidity of these structures is important in the overall determination of the strength margin of safety for the system. If these supports are not rigid, then the first mode of vibration for the system will be lowered and the stresses cause by resonance proportionately high.

Measuring the resonant frequency of the individual units in a vibration facility will characterise the stiffness of the supports and stray-light baffles. The results obtained from these tests will be used to correlate and calibrate FEA modelling of the units. These calibrated unit models are then used to in a model of the entire system to predict the behaviour of the 300-mK strap system. The output of this model will be information on the stresses in the strap and the supports under vibration, prediction of the first mode shape and frequency and importantly on the random vibration interface forces.

This design analysis is used in the design of the system that will proceed into the STM/CQM programme.

Final characterisation of the performance of the system will occur in parallel with the STM programme.

10.2.2 Integrated system testing

Once the design has been frozen, the structural performance of the system will be tested and qualified during the STM programme. Initially, the 300-mK strap system will be integrated into a model of SPIRE that has a mass dummy cooler. SPIRE will then be subjected to a warm vibration at RAL. Accelerometers will be used to correlate the results and predictions from the SPIRE FEA model. This testing will not be able to accurately determine the fidelity of the FEA analysis of the 300-mK system due to the problem of mounting accelerometers onto a lightweight structure without gross changes in the structural response. After the warm vibration test, SPIRE will be tested in a cold vibration facility. These integrated instrument vibration tests will structurally qualify the design of the system. The main indicators that the system is responding as predicted will be the presence of the first several resonances of the 300-mK strap system on the accelerometer mounted on the photometer detector box.

10.3 Optical Testing

The requirement on the optical performance of the 300-mK support system lies in the efficiency with which the stray-light baffles prevent spurious in-band radiation from entering the detector boxes. This will be conducted in a cryostat at UCF. A calibrated photometric detector will be placed inside the cryostat. The stray-light baffle will be exposed to a radiating source and the stray-light shielding efficiency measured. Given that the baffles are assembled in a geometrically similar position to the test baffle in the cryostat, the shielding efficiency in SPIRE will be assumed to be similar.

The shielding effectiveness will be partially tested during the CQM programme. The FTS mechanism has a LED that emits at a wavelength of 500nm. During the test, the amplitude of this LED will be modulated. Any spurious signal detection at the detectors will be classified as being stray-light. If no signal is detected, then the baffles will be deemed to be functioning adequately.

11. Compliance matrix

Requirement Reference	**Description**	**Verification Methods**				
		DM	**STM**	**CQM**	**PFM**	**FS**
STRAP-Req-01	Temperature drop across thermal link between detectors and evaporator cold tip	Test (UCF) Analysis (RAL)	Test (RAL)	Test (RAL)	Test (RAL)	Test (RAL)
STRAP-Req-02	Strap Support and Stray-Light Baffles Parasitic heat load	Test (UCF) Analysis (UCF)		Test (RAL)	Test (RAL)	Inspection (RAL) Similarity (RAL)
STRAP-Req-03	PTC Hardware Parasitic heat load	Analysis (RAL/JPL)		Test (RAL)	Similarity (RAL)	Similarity (RAL)
STRAP-Req-04	The 300-mK Strap system is to be supported entirely from the Level-0 Photometer and Spectrometer Detector Boxes		Inspection (RAL)	Inspection (RAL)	Inspection (RAL)	Inspection (RAL)
STRAP-Req-05	Mass	Analysis (MSSL)		Test (MSSL)	Similarity (RAL)	Similarity (RAL)
STRAP-Req-06	First mode of vibration	Analysis (MSSL)	Test (RAL/MSSL)		Similarity (RAL)	Similarity (RAL)
STRAP-Req-07	Qualification level random vibration loads	Analysis (MSSL)	Test (RAL/MSSL)		Similarity	Acceptance
STRAP-Req-08	Qualification level Sine vibration loads	Analysis (MSSL)	Test (RAL/MSSL)		Similarity	Acceptance
STRAP-Req-09	Interface surface finish		Test (MSSL)		Test (MSSL)	Test (MSSL)

Requirement Reference	**Description**	**Verification Methods**				
		DM	**STM**	**CQM**	**PFM**	**FS**
STRAP-Req-10	BDA Interface vibration loads	Analysis (MSSL)				
STRAP-Req-11	Cooler Interface vibration loads	Analysis (MSSL)				
STRAP-Req-12	BDA Interface static loads	Analysis (MSSL)				
STRAP-Req-13	Cooler Interface static loads	Analysis (MSSL)				
STRAP-Req-14	PTC Accommodation		Inspection	Similarity	Similarity	Similarity
STRAP-Req-15	PTC Envelope		Inspection	Similarity	Similarity	Similarity
STRAP-Req-16	PTC Mass		Test (MSSL)	Similarity	Similarity	Similarity
STRAP-Req-17	Stray-light baffling effectiveness	Test (UCF)	Similarity	Similarity	Similarity	Similarity
STRAP-Req-18	Stray-Light Baffle Opacity	Test (UCF)	Similarity	Similarity	Similarity	Similarity
STRAP-Req-19	Isolation of the Photometer strap from the Sorption Cooler cold tip and the spectrometer strap.	Analysis (MSSL)		Test (RAL)	Test (RAL)	Test (RAL)
STRAP-Req-20	Isolation of the Spectrometer strap from the Sorption Cooler cold tip and the spectrometer strap	Analysis (MSSL)		Test (RAL)	Test (RAL)	Test (RAL)
STRAP-Req-21	Stray capacitance between the spectrometer strap and Sorption Cooler cold tip	Analysis (MSSL)		Test (RAL)	Similarity (RAL)	Similarity (RAL)
STRAP-Req-22	Stray capacitance between the photometer strap and Sorption Cooler cold tip	Analysis (MSSL)		Test (RAL)	Similarity (RAL)	Similarity (RAL)

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